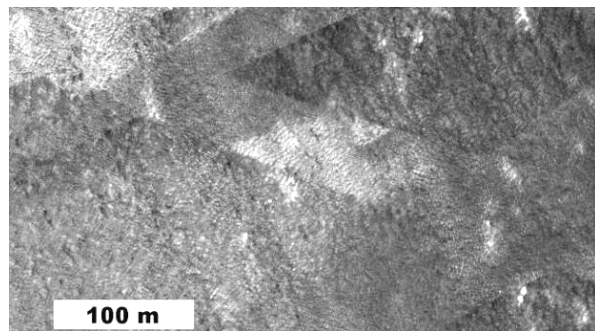


## MRO HIRISE OBSERVATIONS OF RECENT PHENOMENA IN THE NORTH POLAR REGION OF MARS.

Herkenhoff<sup>1</sup>, K. E., Byrne<sup>2</sup>, S., Milkovich<sup>3</sup>, S. M. and Russell<sup>4</sup>, P. S. and the HiRISE Science Team.

<sup>1</sup>Astrogeology Science Center, United States Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001 ([kherkenhoff@usgs.gov](mailto:kherkenhoff@usgs.gov)), <sup>2</sup>Lunar and Planetary Laboratory, University of Arizona, 1629 E. University Blvd., Tucson, AZ 85721 ([shane@lpl.arizona.edu](mailto:shane@lpl.arizona.edu)), <sup>3</sup>Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109 ([Sarah.M.Milkovich@jpl.nasa.gov](mailto:Sarah.M.Milkovich@jpl.nasa.gov)), <sup>4</sup>Center for Earth and Planetary Studies, Smithsonian Institution, P.O. Box 37012, MRC 315, Washington, DC 20013 ([russellp@si.edu](mailto:russellp@si.edu)).

**Introduction:** The High Resolution Imaging Science Experiment (HiRISE) on the Mars Reconnaissance Orbiter (MRO) has observed the north polar region of Mars during 4 summer seasons. Full-resolution HiRISE images are typically 20,000 monochrome pixels (~6 km) wide with color data in the central 4000 pixels [1]. Such HiRISE images of the north polar region with scales of ~30 cm/pixel show morphologic details and reflectance variations indicative of currently active processes. Here we summarize analyses of these observations, focusing on active and recent processes including evolution of frost streaks, the north polar residual cap (NPRC), frost avalanches, and scarp erosion. NPRC craters and the mid-latitude ice-exposing craters tell a self-consistent story of recent ice transport from mid-latitudes to the pole. The observations discussed here highlight the importance of both long- and short-term monitoring of north polar targets to further our understanding of time-variable phenomena in this region.

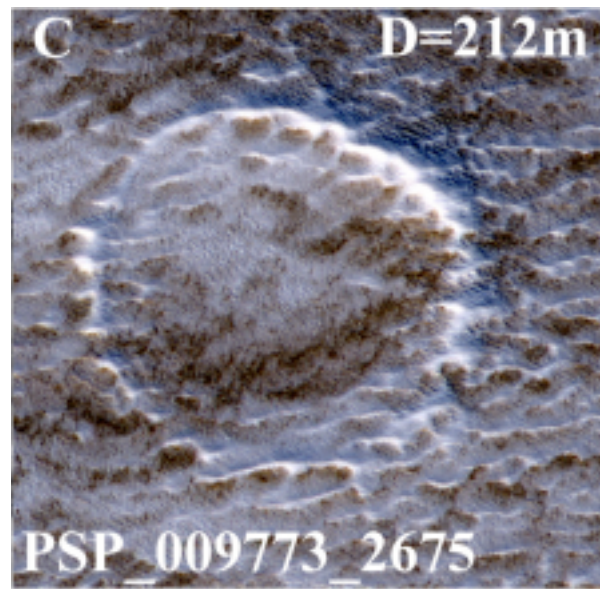


**Figure 1:** Part of red HiRISE image PSP\_009273\_2610 showing complex streak superposition at 80.8°N, 330.6°E.

**Polar Streaks:** Bright and dark streaks have been observed at the periphery of the NPRC by previous Mars orbiters and were the target of several HiRISE observations. The complex interactions between overlapping bright and dark streaks in some of these HiRISE images (Fig. 1) indicate that formation of the streaks involves processes more complex than the emplacement of dark veneers proposed by Rodriguez *et al.* [2]. Bright and dark streaks are seen to evolve during the northern summer, evidence for active eolian redistribution of frost and perhaps darker (non-volatile)

dust or sand. But the sharp boundaries of the streaks remain unexplained.

**Residual Ice Cap:** The north polar residual cap (NPRC) on Mars has long been known to be composed of water ice [3]. The NPRC may provide a link between the current martian climate and the historical climate recorded within the layers of the underlying north polar layered deposits (NPLD). Relatively dark patches observed within the NPRC during the summer indicate that the cap is very thin or very transparent in places.



**Figure 2.** Degraded 212 m diameter crater on north polar residual cap. Note that crater rimcrest has been modified but not completely removed by erosion, and that crater has been partly infilled.

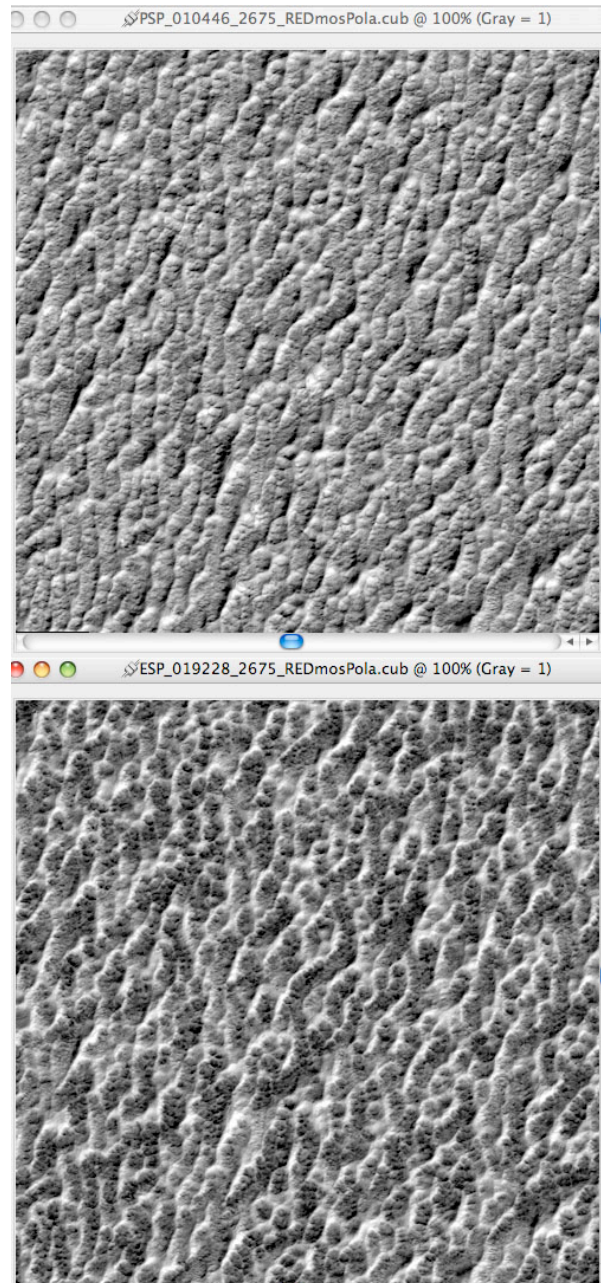
**Resurfacing rate.** Counts of craters in Viking Orbiter and MRO Context Camera images indicate that the craters on the NPRC accumulated within the last 20,000 years or less [4,5]. HiRISE images of the NPRC show few fresh craters. Based on HiRISE and Context Camera observations of variously degraded craters on the NPRC, average accumulation rates are estimated to be 4-7 mm/yr within these craters [5]. Other degradation processes have probably been active on the NPRC, so this rate is an upper bound on the

resurfacing rate, with lower rates likely on the intra-crater NPRC surface. HiRISE images of degraded craters show evidence for multiple mechanisms of crater degradation. For example, Fig. 2 shows a crater that has been almost completely infilled, yet the crater rim is still visible. Evidently deposition is dominant within the craters, while erosional processes dominate on the surrounding cap surface, consistent with spectroscopic observations of coarse-grained (and therefore old) ice on the cap [6].

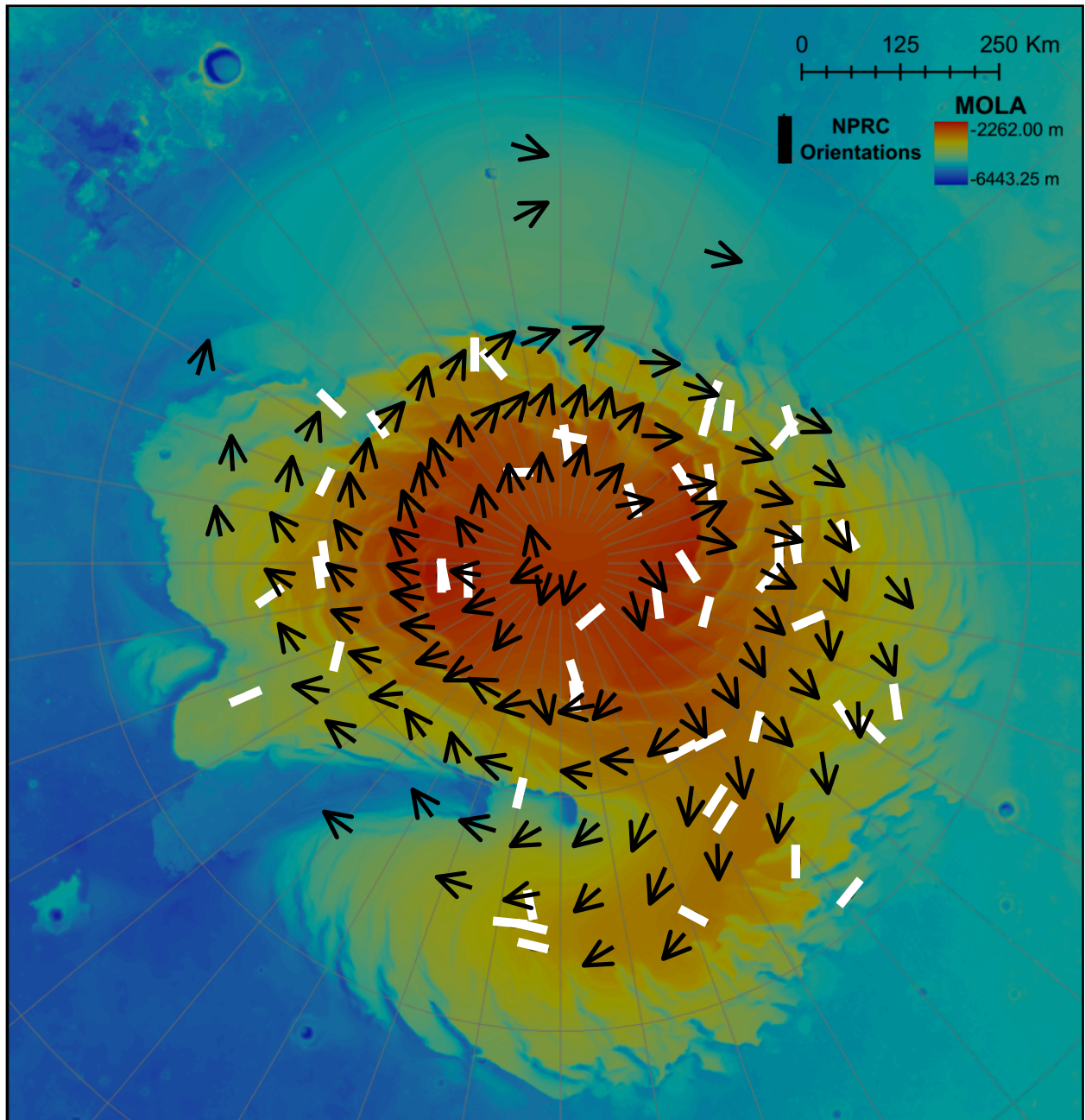
*Cap monitoring.* It is likely that NPRC resurfacing is spatially and temporally episodic rather than continuous, and that annual changes may be detectable at HiRISE image resolutions. Therefore, a campaign of HiRISE observations of four NPRC targets near 87°N latitude (the maximum latitude of the MRO ground track) was initiated during the Martian northern summer of 2008 and continued during the summers of 2010 and 2012. The images acquired during this campaign, with nearly nadir viewing geometry and similar solar azimuth, have been searched for evidence for current redistribution of NPRC material. Only minor albedo changes are observed, consistent with the resurfacing rate discussed above. In some areas, the overall albedo of the NPRC decreased between Mars Years 29 and 30 (Fig. 3), consistent with annealing of water ice grains. Comparison of simultaneously-acquired HiRISE, CRISM, and MARCI data indicates that their absolute radiometry agrees to within 10%, so we are confident that albedos measured from calibrated HiRISE images are accurate to 20%. The data analyzed here have not been corrected for atmospheric scattering, but such effects cannot explain the relative changes in albedo (troughs vs. ridges) seen in Figure 3.

*Orientation of surface features.* The quasi-regular spacing of the NPRC surface texture lends itself to automated analysis via 2D FFT. This technique reconstructs an image using many sinusoidal functions of varying wavelengths and power and allows us to quickly and quantitatively identify the dominant orientation of the surface texture. Images of the NPRC near troughs tend to show surface textures (e.g., Fig. 3) that trend in the same direction as the troughs. However, images located in the polar flats (i.e., Gemini Lingula and the polar dome) do not have any general trend (Fig 4). Howard [4] examined the orientations of frost streaks in Viking imagery to infer the direction of the wind over the polar deposits. When we compare these results to our orientation results, we see that near the troughs, the wind tends to run perpendicular to the surface texture orientation (Fig. 4). Thus, wind direction may have an influence on texture orientation. However, there is no general relationship between surface texture orientation and wind direction away from

the troughs, so wind direction cannot be the only factor determining texture orientation. It is likely that many processes are at work shaping the surface texture, and thus their effects are tangled together. Surface frost, elevation or latitude, and wind direction all appear to have significant effects.



**Figure 3.** HiRISE images of the north polar residual cap near 87°N, 270°E, illuminated nearly identically from lower right. (top) PSP\_010446\_2675, taken at  $L_s=143.7^\circ$  in Mars Year 29 (2008), Lambert albedo = 0.46. (bottom) ESP\_019228\_2675, taken at  $L_s=142.4^\circ$  in Mars Year 30 (2010), Lambert albedo = 0.40.



**Figure 4:** Orientation analysis results (white lines) compared to wind directions inferred from frost streaks in Viking images by Howard [7] (black arrows).

**CO<sub>2</sub> frost-dust falls and avalanches:** Nine frost-dust avalanches were observed in northern spring, Mars Year 29 (2008), between  $L_s$  27° and 39° [8]. Only one image was taken earlier in the season that year ( $L_s$ =14°). In Mars Year 30 (2010), imaging could not start before  $L_s$  ~25° due to prolonged MRO safing, but 27 events of various sizes were identified, ceasing by  $L_s$ =50°. Several of these events occurred at scarps other than the very steep section of Olympia Rupes

where avalanches were discovered in Year 29, although most were on that scarp. All scarps were steep (> 40°) and fractured. In Mars Year 31, 13 sites considered most likely to show an avalanche based on previous years were intensely monitored throughout early spring. In addition, during the period  $L_s$ =19.2° - 25.6°, 27 additional locations spread around the periphery of Planum Boreale and Casma Boreale were imaged, yielding a snapshot of geographically and

morphologically diverse scarps at a common moment in time. Seven images showing avalanches at the discovery scarp have been identified through  $L_s=42^\circ$ , with the first occurring at  $L_s=8.9^\circ$  (Fig. 5). The extension of this onset time to such an early date suggests this may be one of those processes that begins in response to faint, low-energy insolation [e.g., 9, 10]. Only a few avalanches have been detected on other scarps so far this year. A complete spatial, seasonal, and inter-annual comparison over the three years provides an increasingly robust database from which to analyze these features.



**Figure 5.** HiRISE image ESP\_024282\_2640, taken at  $L_s=8.9^\circ$  with illumination from upper left. Steep, darker scarp at bottom slopes toward top of image.

Loosely coincident timing with local and polar regional  $\text{CO}_2$  frost sublimation generally suggests a causal relationship. This and an apparent origin location on the scarp face suggest the events are triggered by sublimation-related or scarp-proximal atmospheric disturbances (e.g., wind gusts). Although there is good evidence of wind gusts on the plateau above the scarp [8], no instances of particle clouds going over the scarp lip have ever been observed.

The Year 30 observation campaign has increased confidence in the ending  $L_s$  of these events. Thermal models of surface  $\text{CO}_2$  balance and sublimation rate, suggest that such steep scarps should be free of  $\text{CO}_2$  during avalanche season, although upper shallower sections ( $\sim 30^\circ$ ) may retain  $\text{CO}_2$  through part of the season [see also 11]. Constraints on nearby  $\text{CO}_2$  presence are provided by seasonal CRISM observations. However, spectral analysis of steep scarps is complicated by their small size, high relief, and poor early-spring coverage. The scarps are far from smooth, and crevasses, recesses, and fractures are ubiquitous. The discrete, sudden, isolated nature of these events suggests a non-uniform process, likely involving a build up of factors before a disturbance. These observations suggest  $\text{CO}_2$  persisting in dark niches on the scarp may be retained until disruption by building sublimation pressure or thermal cracking of water ice in the NPLD.

**Conclusions:** The HiRISE north polar imaging campaign demonstrates that surface materials are mobilized annually and that the north polar region is currently active. Observations discussed here highlight the importance of both long- and short-term monitoring of north polar targets to further our understanding of time-variable phenomena in this region.

#### References:

- [1] McEwen, A. S. *et al.* (2007) *JGR* **112**, doi:10.1029/2005JE002605.
- [2] Rodriguez, J.A.P. *et al.* (2007) *Mars* **3**, 29.
- [3] Jakosky, B. M. and Haberle R. M. (1992) In *Mars* (H.H. Kieffer *et al.*, Eds.), pp. 969-1016. Univ. Arizona Press, Tucson.
- [4] Herkenhoff, K. E. and Plaut, J. J. (2000) *Icarus* **144**, 243.
- [5] Banks, M. *et al.* (2010) *JGR* **115**, E08006, doi:10.1029/2009JE003523.
- [6] Lengevin, Y. *et al.* (2005) *Science* **307**, 1584-86.
- [7] Howard, A. (2000) *Icarus* **144**, 267-288.
- [8] Russell, P. S. *et al.* (2008) *GRL* **35**, L23204, doi:10.1029/2008GL035790.
- [9] Hansen C. *et al.* (2010) *Icarus*, **205**, 283-295.
- [10] Hansen C. *et al.* (2011) *Science*, **331**, 6017, 575-578.
- [11] Becerra P. *et al.* (2011) *5<sup>th</sup> Mars Polar Sci. Conf.*, Abstract #6024.

**Acknowledgements:** This research was supported by NASA's Mars Reconnaissance Orbiter project. A portion of this work was carried out at the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration.